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**Yang et al.**

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(54) **REGULATION CIRCUIT ASSOCIATED WITH SYNCHRONOUS RECTIFIER PROVIDING CABLE COMPENSATION FOR THE POWER CONVERTER AND METHOD THEREOF**

(58) **Field of Classification Search**  
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See application file for complete search history.

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 319 days.

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**Related U.S. Application Data**

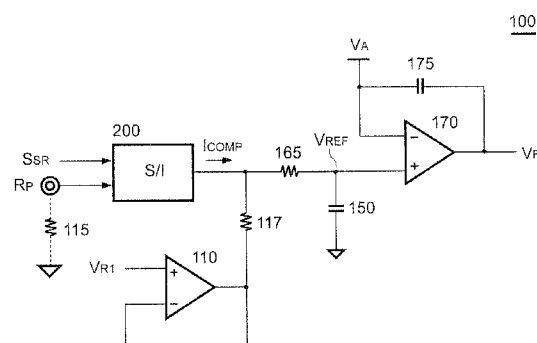
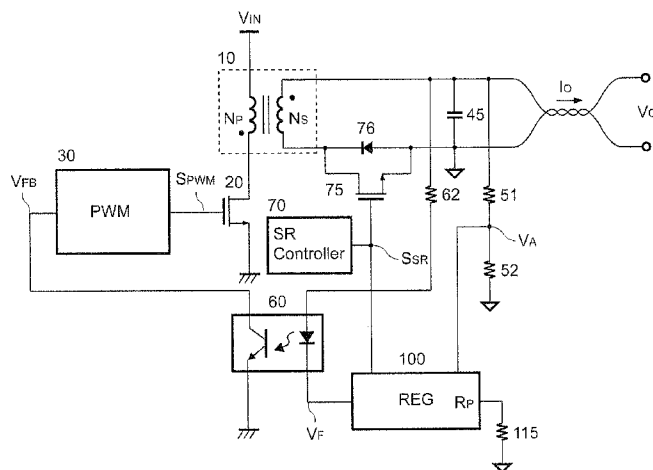
(60) Provisional application No. 61/511,651, filed on Jul. 26, 2011.

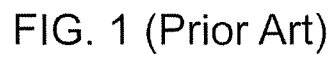
(57) **ABSTRACT**

A regulation circuit of a power converter for cable compensation according to the present invention comprises a signal generator generating a compensation signal in accordance with a synchronous rectifying signal. An error amplifier has a reference signal for generating a feedback signal in accordance with an output voltage of the power converter. The compensation signal is coupled to program the reference signal. The feedback signal is coupled to generate a switching signal for regulating an output of the power converter. The regulation circuit of the present invention compensates the output voltage without a shunt resistor to sense the output current of the power converter for reducing power loss.

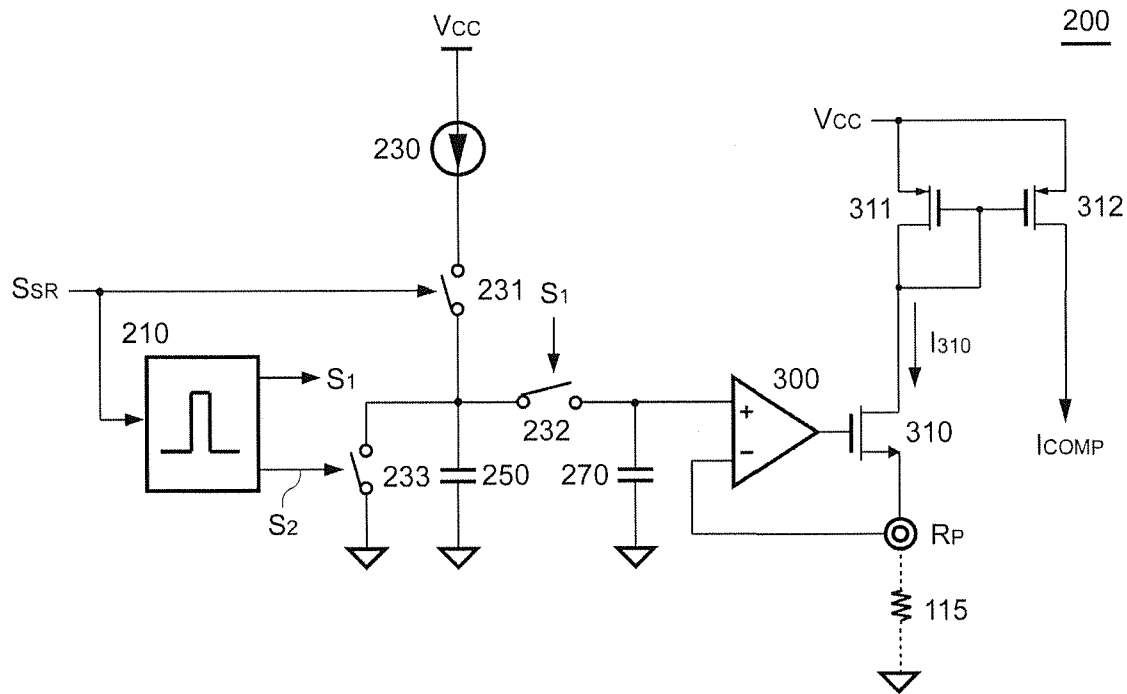
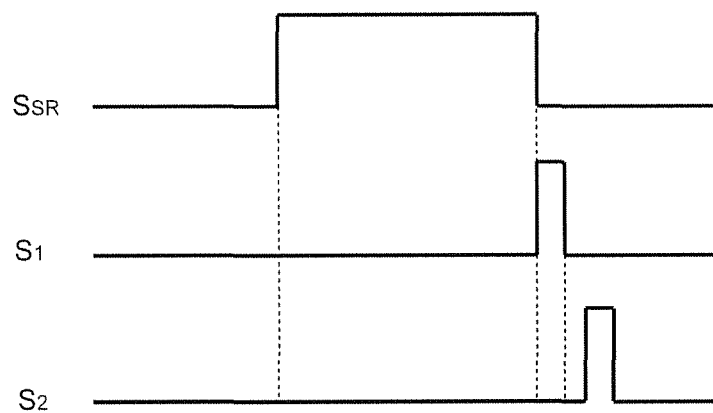
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CPC .. **H02M 3/33592** (2013.01); **H02M 2001/0025** (2013.01); **Y02B 70/1475** (2013.01)

**15 Claims, 3 Drawing Sheets**







**U.S. Patent****Jul. 7, 2015****Sheet 3 of 3****US 9,077,258 B2****FIG. 4****FIG. 5**

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# REGULATION CIRCUIT ASSOCIATED WITH SYNCHRONOUS RECTIFIER PROVIDING CABLE COMPENSATION FOR THE POWER CONVERTER AND METHOD THEREOF

## REFERENCE TO RELATED APPLICATIONS

This application is based on Provisional Patent Application No. 61/511,651, filed 26 Jul. 2011, currently pending.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention is related to a regulation circuit, especially to a regulation circuit associated with a synchronous rectifier providing cable compensation for the power converter.

### 2. Description of the Related Art

FIG. 1 shows a prior art of a power converter. A PWM controller (PWM) 30 generates a switching signal  $S_{PWM}$  to switch a transformer 10 having a primary winding  $N_p$  and a secondary winding  $N_s$  via a power transistor 20 in accordance with a feedback signal  $V_{FB}$  for regulating the output of the power converter. The primary winding  $N_p$  of the transformer 10 is coupled to receive an input voltage  $V_{IN}$ . The feedback signal  $V_{FB}$  is generated by an opto-coupler 60 in response to the output voltage  $V_O$  of the power converter. The opto-coupler 60 is controlled by an error amplifier 50. The error amplifier 50 generates a signal  $V_F$  coupled to control the opto-coupler 60. The error amplifier 50 includes a reference signal  $V_R$  supplied with a positive input terminal of the error amplifier 50 for regulating the output voltage  $V_O$ . The output voltage  $V_O$  is coupled to a negative input terminal of the error amplifier 50 via a voltage divider developed by resistors 51 and 52. A capacitor 53 is coupled between the negative input terminal of the error amplifier 50 and an output terminal of the error amplifier 50.

The secondary winding  $N_s$  is coupled to an output terminal of the power converter to generate the output voltage  $V_O$ . A rectifier 40 is coupled to one terminal of the secondary winding  $N_s$ . An output capacitor 45 is coupled to the other terminal of the secondary winding  $N_s$  and the output terminal of the power converter to generate the output voltage  $V_O$ . A resistor 62 is coupled from the capacitor 45 and the rectifier 40 to the opto-coupler 60.

Generally, the output cable of the power converter has a voltage drop proportional to its output current. Sensing the output current to offset the voltage drop is an approach for the output cable compensation. However, it will generate a significant power loss while sensing the output current by using a shunt resistor. The present invention provides a method and apparatus to compensate the output voltage without the need of sensing the output current of the power converter by the shunt resistor.

## BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to provide a regulation circuit and a method with output cable compensation for the power converter. The regulation circuit and method compensate the output voltage without a shunt resistor to sense the output current of the power converter for reducing power loss.

The regulation circuit with output cable compensation for the power converter according to the present invention comprises a signal generator and an error amplifier. The signal generator generates a compensation signal in accordance with a synchronous rectifying signal. The error amplifier has

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a reference signal for generating a feedback signal in accordance with an output voltage of the power converter. The compensation signal is coupled to program the reference signal. The feedback signal is coupled to generate a switching signal for regulating an output of the power converter.

A method for the regulation circuit of the power converter according to the present invention comprises receiving the synchronous rectifying signal for generating the compensation signal, compensating the reference signal of the error amplifier of the regulation circuit in accordance with the compensation signal, and generating the feedback signal in accordance with the reference signal and the output voltage of the power converter. The feedback signal is coupled to generate the switching signal for regulating the output of the power converter.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. 1 shows a circuit diagram of a conventional power converter.

FIG. 2 shows a circuit diagram of a preferred embodiment of a power converter in accordance with the present invention.

FIG. 3 shows a circuit diagram of a preferred embodiment of the regulation circuit in accordance with the present invention.

FIG. 4 shows a circuit diagram of a preferred embodiment of the signal generator in accordance with the present invention.

FIG. 5 shows the waveforms of the SR signal  $S_{SR}$  and the pulse signals  $S_1$  and  $S_2$  of the pulse generator in accordance with the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. 2 is a circuit diagram of a preferred embodiment of the power converter having a regulation circuit 100 according to the present invention. The power converter comprises the transformer 10, the power transistor 20, the PWM controller (PWM) 30, the opto-coupler 60, a synchronous rectifying (SR) controller 70, a power transistor 75, and the regulation circuit (REG) 100. The power transistor 20 is coupled from the primary winding  $N_p$  of the transformer 10 to the ground for switching the transformer 10. The PWM controller 30 generates the switching signal  $S_{PWM}$  to switch the power transistor 20 in accordance with the feedback signal  $V_{FB}$  for regulating the output (output voltage  $V_O$  and/or the output current  $I_O$ ) of the power converter.

The opto-coupler 60 is coupled to the secondary winding  $N_s$  of the transformer 10 through the resistor 62. The opto-coupler 60 generates the feedback signal  $V_{FB}$  coupled to the PWM controller 30 in response to the output voltage  $V_O$ . The secondary winding  $N_s$  is coupled to the output terminal of the power converter to generate the output voltage  $V_O$ . The output capacitor 45 is coupled to the secondary winding  $N_s$  and the output terminal of the power converter to generate the output voltage  $V_O$ . The output voltage  $V_O$  is outputted to the load through the output cable. The output current  $I_O$  of the power converter flows through the output cable.

The power converter has a synchronous rectifying circuit to improve the power efficiency of the power converter. The synchronous rectifying circuit includes the synchronous rectifying controller 70 and the power transistor 75 having a parasitic diode 76. The power transistor 75 is used for a synchronous rectifier to replace the rectifier 40 (shown in

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FIG. 1) for rectification. A drain terminal of the power transistor **75** is coupled to the secondary winding  $N_{S2}$  and a source terminal of the power transistor **75** is coupled to the output terminal of the power converter. The parasitic diode **76** is coupled between the drain terminal and the source terminal of the power transistor **75**. The synchronous rectifying controller **70** generates a synchronous rectifying signal (SR signal)  $S_{SR}$  coupled to a gate terminal of the power transistor **75** to control the on/off of the power transistor **75**.

The detail operation of the synchronous rectifying circuit can be found in the prior art of "Synchronous rectification circuit for power converters", U.S. Pat. No. 7,440,298. Refer to equation (9) of this prior art, it is,

$$T_{discharge} = \frac{V_S}{V_O} \times T_{charge} \quad (1)$$

where the  $T_{charge}$  is equal to the on-time  $T_{ON}$  of the switching signal  $S_{PWM}$ ;  $T_{discharge}$  is the "turn on period" of the SR signal  $S_{SR}$ . The  $V_S$  is the magnetized voltage that is correlated to the input voltage  $V_{IN}$  of the power converter. Thus, the equation (1) can be rewritten as equation (2),

$$T_{SSR} = \frac{K \times V_{IN}}{V_O} \times T_{ON} \quad (2)$$

where K is a constant.

Refer to an output power  $P_O$  of the flyback power converter, it can be expressed as,

$$P_O = V_O \times I_O = \frac{V_{IN}^2 \times T_{ON}^2}{2 \times L_P \times T} \quad (3)$$

where  $L_P$  is the inductance of the primary winding  $N_P$  of the transformer **10**; T is the switching period of the switching signal  $S_{PWM}$ .

In accordance with the equations (2) and (3), if the output voltage  $V_O$  is fixed value, then the period  $T_{SSR}$  ("turn on period" of the SR signal  $S_{SR}$ ) is correlated to the output current  $I_O$ . In other words, the SR signal  $S_{SR}$  is correlated to the output current  $I_O$ . Therefore, the SR signal  $S_{SR}$  can be used instead of the output current  $I_O$  to control the output voltage  $V_O$  for the cable compensation.

The regulation circuit **100** is coupled to receive the SR signal  $S_{SR}$  and the signal  $V_A$  for generating the signal  $V_F$ . The signal  $V_F$  is future coupled to drive the opto-coupler **60** and generate the feedback signal  $V_{FB}$ . The signal  $V_A$  is produced in accordance with the output voltage  $V_O$  via the voltage divider developed by the resistors **51** and **52**. Therefore, the regulation circuit **100** is used for generating the feedback signal  $V_{FB}$  in accordance with the output voltage  $V_O$ . The voltage drop of the output voltage  $V_O$  in the output cable can be compensated by the control of the SR signal  $S_{SR}$ . Further, a resistor **115** is coupled to a terminal  $R_P$  of the regulation circuit **100**.

FIG. 3 is a circuit diagram of a preferred embodiment of the regulation circuit **100** according to the present invention. A signal generator (S/I) **200** is coupled to receive the SR signal  $S_{SR}$  for generating a compensation signal  $I_{COMP}$ . The resistor **115** is coupled to the terminal  $R_P$  of the signal generator **200** to determine the ratio of signal generation. The resistor **115** is used for programming the level of the compensation signal

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$I_{COMP}$  in accordance with the SR signal  $S_{SR}$ . An output terminal of a buffer amplifier **110** having a reference voltage  $V_{R1}$  supplied with a positive input terminal of the buffer amplifier **110** is coupled to a resistor **117**. The resistor **117** is further coupled to an output terminal of the signal generator **200**. A negative input terminal of the buffer amplifier **110** is coupled to the output terminal of the buffer amplifier **110** and the resistor **117**. The compensation signal  $I_{COMP}$  and the resistor **117** are utilized to generate a compensation voltage at the resistor **117**.

A resistor **165** and a capacitor **150** develop a filter coupled to the output terminal of the signal generator **200** and the resistor **117**. The resistor **165** is coupled from the output terminal of the signal generator **200** and the resistor **117** to a terminal of the capacitor **150**. The other terminal of the capacitor **150** is coupled to the ground. Through the filter, a reference signal  $V_{REF}$  is generated at the capacitor **150**.

$$V_{REF} = V_{R1} + (I_{COMP} \times R_{117}) \quad (4)$$

The capacitor **150** of the filter is used for filtering the reference signal  $V_{REF}$ . According to equation (4), the reference signal  $V_{REF}$  is correlated to the compensation signal  $I_{COMP}$ . Therefore, the compensation signal  $I_{COMP}$  can program and compensate the reference signal  $V_{REF}$ , and the reference signal  $V_{REF}$  is programmable in response to the output current  $I_O$  (as shown in FIG. 2) due to the compensation signal  $I_{COMP}$  is correlated to the SR signal  $S_{SR}$  and the SR signal  $S_{SR}$  is correlated to the output current  $I_O$ . Further, according to equation (4), the reference signal  $V_{REF}$  is further correlated to the reference voltage  $V_{R1}$  of the buffer amplifier **110**. Therefore, the buffer amplifier **110** is coupled to the compensation signal  $I_{COMP}$  for generating the reference signal  $V_{REF}$ .

An error amplifier **170** is coupled to receive the reference signal  $V_{REF}$  and the signal  $V_A$  to generate the signal  $V_F$  for generating the feedback signal  $V_{FB}$  (as shown in FIG. 2). A positive input terminal and a negative input terminal of the error amplifier **170** receive the reference signal  $V_{REF}$  and the signal  $V_A$  respectively. An output terminal of the error amplifier **170** generates the signal  $V_F$ . A capacitor **175** is coupled between the negative input terminal of the error amplifier **170** and the output terminal of the error amplifier **170**.

FIG. 4 is a circuit diagram of a preferred embodiment of the signal generator **200** according to the present invention. A pulse generator **210** receives the SR signal  $S_{SR}$  and generates pulse signals  $S_1$  and  $S_2$  in response to the SR signal  $S_{SR}$ . The waveforms of the pulse signals  $S_1$  and  $S_2$  are shown in FIG. 5. The first pulse signal  $S_1$  is enabled when the SR signal  $S_{SR}$  is disabled. Once the first pulse signal  $S_1$  is disabled, the second pulse signal  $S_2$  is enabled after a delay time. The SR signal  $S_{SR}$  is further coupled to control a charge circuit to charge a capacitor **250** for providing a voltage. The voltage provided by the capacitor **250** is correlated to the SR signal  $S_{SR}$ . The charge circuit includes a current source **230** and a charge switch **231**. The current source **230** is coupled between a supply voltage  $V_{CC}$  and the charge switch **231** to charge the capacitor **250** through the charge switch **231**. The capacitor **250** is coupled from the charge switch **231** to the ground. The charge switch **231** is controlled by the SR signal  $S_{SR}$ .

The first pulse signal  $S_1$  is coupled to control a sample switch **232** for sampling the voltage of the capacitor **250** to a capacitor **270**. The sample switch **232** is coupled between the capacitor **250** and the capacitor **270**. The capacitor **270** is further coupled to the ground.

The second pulse signal  $S_2$  is coupled to control a discharge switch **233** for discharging the capacitor **250**. The discharge switch **233** is coupled between the capacitor **250** and the ground. The voltage of the capacitor **270** is correlated to the

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voltage of the capacitor **250**. The capacitor **270** is further coupled to a voltage to current converter to convert the voltage of the capacitor **270** to a current  $I_{310}$  for generating the compensation signal  $I_{COMP}$ . In other words, the voltage to current converter converts the voltage of the capacitor **250** to the current  $I_{310}$  for generating the compensation signal  $I_{COMP}$ . The voltage to current converter includes an operational amplifier **300** and a transistor **310**. The resistor **115** (at RP terminal) is coupled to the voltage to current converter.

The capacitor **270** is coupled to a positive input terminal of the operational amplifier **300**. A negative input terminal of the operational amplifier **300** is coupled to a source terminal of the transistor **310** and the resistor **115** through the RP terminal. The source terminal of the transistor **310** is coupled to the resistor **115** through the RP terminal. The voltage to current converter converts the voltage of the capacitor **270** to the current  $I_{310}$  at a drain terminal of the transistor **310** in accordance with the resistance of the resistor **115** (at RP terminal). The resistor **115** is utilized to program the current  $I_{310}$  in accordance with the SR signal  $S_{SR}$  for programming the level of the compensation signal  $I_{COMP}$ .

A gate terminal of the transistor **310** is controlled by an output terminal of the operational amplifier **300** for producing the current  $I_{310}$ . The current  $I_{310}$  is further coupled to a current mirror formed by transistors **311** and **312**. The current mirror generates the compensation signal  $I_{COMP}$ . Source terminals of the transistors **311** and **312** are coupled to the supply voltage  $V_{CC}$ . Gate terminals of the transistors **311** and **312** and drain terminals of the transistors **310** and **311** are coupled together. A drain terminal of the transistor **312** generates the compensation signal  $I_{COMP}$ .

Although the present invention and the advantages thereof have been described in detail, it should be understood that various changes, substitutions, and alternations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims. That is, the discussion included in this invention is intended to serve as a basic description. It should be understood that the specific discussion may not explicitly describe all embodiments possible; many alternatives are implicit. The generic nature of the invention may not fully explained and may not explicitly show that how each feature or element can actually be representative of a broader function or of a great variety of alternative or equivalent elements. Again, these are implicitly included in this disclosure. Neither the description nor the terminology is intended to limit the scope of the claims.

What is claimed is:

1. A regulation circuit of a power converter, comprising:
  - a signal generator generating a compensation signal in accordance with a synchronous rectifying signal; and
  - an error amplifier having a reference signal for generating a feedback signal in accordance with an output voltage of the power converter;
 wherein the compensation signal is coupled to program the reference signal; the feedback signal is coupled to generate a switching signal for regulating an output of the power converter.
2. The regulation circuit as claimed in claim 1, further comprising:
  - a resistor coupled to the signal generator for programming the level of the compensation signal in accordance with the synchronous rectifying signal.
3. The regulation circuit as claimed in claim 1, further comprising:
  - a filter coupled to the reference signal for filtering the reference signal.

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4. The regulation circuit as claimed in claim 3, wherein the filter comprises:

a capacitor for filtering the reference signal.

5. The regulation circuit as claimed in claim 1, wherein the synchronous rectifying signal is utilized to control a power transistor coupled to the power converter; wherein the power transistor is used for a synchronous rectifier.

6. The regulation circuit as claimed in claim 1, wherein the synchronous rectifying signal is correlated to an output current of the power converter.

7. The regulation circuit as claimed in claim 1, further comprising:

A buffer amplifier having a reference voltage and coupled to the compensation signal for generating the reference signal.

8. The regulation circuit as claimed in claim 1, wherein the signal generator comprises:

a capacitor providing a voltage for generating the compensation signal; and

a charge circuit charging the capacitor in response to the synchronous rectifying signal for providing the voltage; wherein the voltage is correlated to the synchronous rectifying signal.

9. The regulation circuit as claimed in claim 8, wherein the signal generator further comprises:

a voltage to current converter converting the voltage to a current for generating the compensation signal; and

a resistor coupled to the voltage to current converter to program the current in accordance with the synchronous rectifying signal for programming the level of the compensation signal.

10. A method for a regulation circuit of a power converter, comprising:

receiving a synchronous rectifying signal for generating a compensation signal;

compensating a reference signal of an error amplifier of the regulation circuit in accordance with the compensation signal; and

generating a feedback signal in accordance with the reference signal and an output voltage of the power converter; wherein the feedback signal is coupled to generate a switching signal for regulating an output of the power converter.

11. The method as claimed in claim 10, further comprising: programming the level of the compensation signal in accordance with the synchronous rectifying signal.

12. The method as claimed in claim 10, wherein the synchronous rectifying signal is utilized to control a power transistor coupled to the power converter; wherein the power transistor is used for a synchronous rectifier.

13. The method as claimed in claim 10, wherein the synchronous rectifying signal is correlated to an output current of the power converter.

14. The method as claimed in claim 10, further comprising: charging a capacitor in response to the synchronous rectifying signal to provide a voltage for generating the compensation signal;

wherein the voltage is correlated to the synchronous rectifying signal.

15. The method as claimed in claim 14, further comprising: converting the voltage to a current for generating the compensation signal; and

programming the current in accordance with the synchronous rectifying signal for programming the level of the compensation signal.

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